Mapping and characterization of block-on-block ophiolitic mélange, Oregon Caves National Monument and surrounding areas, southwestern Oregon

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ABSTRACT

The mélange of the Rattlesnake Creek Terrane (RCT) contains vast compositional and structural variability, making specific further subdivisions within the large terrane difficult to characterize. The Oregon Caves National Monument and surrounding areas encompass previously undescribed portions of the RCT and the contact between the Triassic rock of the mélange and the Jurassic rocks of the intruded Greyback Pluton. Detailed, GPS-based field mapping of the Oregon Caves area was conducted in the summer of 2011 by four National Park Service volunteers. The metamorphosed marine rocks of the RCT found in the mapping area do not reflect the most common and well described relationships within the mélange. Rather than a block-in-matrix mélange, the rocks of the Oregon Caves and surrounding areas are characterized by a block-on-block structure. Serpentinite occurs as isolated lenses and thus is not supporting blocks in a mélange. Geographic connections between the block-on-block mélange in the current study area and other block-on-block portions of the RCT may lead to successful delineations within the RCT and have implications for multi-phase mélange formation.

INTRODUCTION

At 4000 feet above sea level, the Oregon Caves National Monument is situated high within the Klamath Mountains (Fig. 1). The Klamaths of southern Oregon and northern

California are built from accreted oceanic material thrust onto the North American plate during Mesozoic subduction. The subduction complex includes matrix-supported mélange, block-on-block mélange, and cohesive terranes such as the Josephine Ophiolite.

Figure 1. Location map of the Oregon Caves National Monument. From Barnard, 2007.

Existing geologic maps of the Oregon Caves National Monument and surrounding areas offer inconsistent interpretations of the varied geology of the Rattlesnake Creek Terrane (RCT). Through detailed field mapping and review of literature, this project seeks to produce a bedrock map accompanied by detailed rock descriptions and a contextualized history of this portion of the RCT.

GEOLOGIC CONTEXT

The Klamath Mountains geologic province is divided into four thrust-bound lithic belts first described by Irwin in 1960 (Snoke and Barnes, 2006). From east to west these are the Eastern Paleozoic, Central Metamorphic, Western Paleozoic and Triassic, and

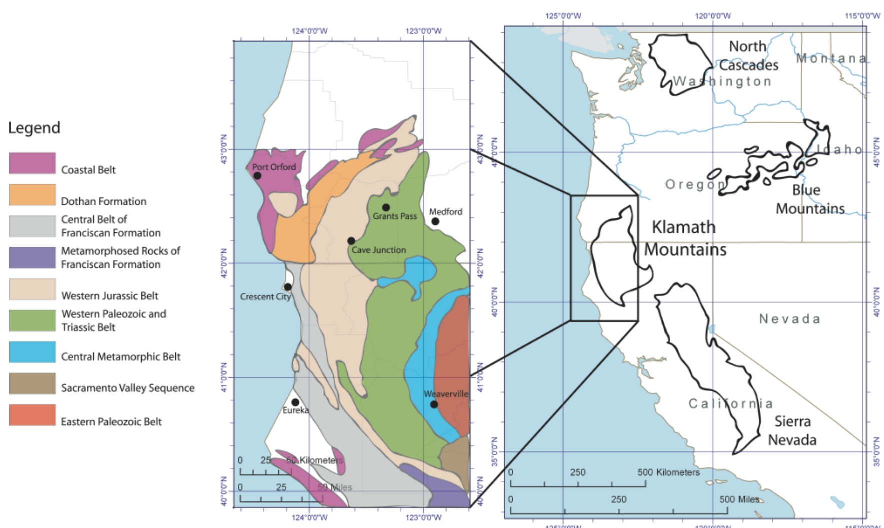

Figure 2. Lithic belts of the Klamath Mountains geologic province. (Barnard, 2007; modified from Snoke and Barnes, 2006)

Western Jurassic. The study area is located within the Western Paleozoic and Triassic lithic belt, which is further subdivided into tectonostratigraphic terranes separated by east-dipping thrust faults (Fig. 2). The Rattlesnake Creek Terrane (RCT) is the westernmost, youngest, and stratigraphically lowest of these terranes and includes the study area. The Salt Creek thrust separates the RCT from the Western Hayfork Terrane to the east. To the west the RCT is bounded by the Orleans thrust, which divides the Western Paleozoic and Triassic lithic belt from the Western Jurassic lithic belt (Snoke and Barnes, 2006).

As described in Wright and Wyld (1994), the Rattlesnake Creek Terrane consists of a lower serpentinite-matrix mélange and an upper cover sequence of coherent volcanic, hemipelagic, and clastic rocks. The coherent cover sequence is late Triassic to early Jurassic in age. The Wooley Creek suite of plutons intrudes both the lower mélange unit and the upper cover sequence of the RCT. The Wooley Creek suite is represented in the mapping area by the 157-160 Ma Greyback pluton.

The basement mélange of the RCT is ~50% serpentinite matrix with 1 cm^2 to 0.03 km^2 blocks of greenstone, amphibolite, pillow basalt, marble and chert. The nature of the mélange changes with proximity to the cover sequence. The composition of the blocks transitions from dominantly igneous and metamorphic to sedimentary and volcanic. The ratio of matrix to block decreases until serpentinite is present only as veins. The cover sequence is further divided into informal assemblages: the lower Salt Creek and upper Dubakella Mt. The older Salt Creek assemblage is composed of ~50% interbedded sedimentary rocks and ~50% basalt. The younger Dubakella Mt. assemblage is dominated by mafic and felsic volcanics. (Wright and Wyld, 1994)

Donato, et al. (1996) correlates parts of the former Applegate terrane with the RCT, specifically in the Bolan Lake area. Here, the mélange of the RCT is block-on-block rather than supported by a serpentinite matrix. The meter- to kilometer- scale blocks are serpentinite, gabbro, basalt, volcanoclastic rocks, chert, siliceous argillite, and marble. The rocks in this area are metamorphosed to greenschist facies. Further to the south, the Californian Marble Mountain terrane has also been correlated with the RCT. Donato (1987) identified similar rocks types, but found no serpentinite matrix, indicating that the Marble Mountains terrane may represent a coherent block end-member of the RCT.

The three descriptions of the RCT and its correlatives illuminate the textural and compositional variability of this terrane. The current research seeks to place the study area and the included Oregon Caves National Monument within a described subset of the RCT.

DATA COLLECTION AND METHODS

Traverses follow road cuts, stream cuts, and ridges, which offer the highest exposure of rock in the otherwise densely forested area. Rocks were identified using field identification techniques without the assistance of thin sections or chemical analysis. Outcrop locations were marked using a hand-held Garmin GPS unit. Using DNR Garmin software, waypoints were uploaded to an ESRI ArcMap GIS 9.3.1 shapefile, which formed the basis of the geologic map.

RESULTS

The dense forest of the Klamath Mountains obscures the enigmatic rocks of the Rattlesnake Creek Terrane, creating exposure issues in an already complex area. These outcrops generally contain only one rock type and thus do not show contacts between rock units. Rock unit distinctions are based on field identifications, rather than petrographic or chemical data. Outcrops are generally massive and weathered; structural data was collected at only 5 of the 459 mapped locations. Planar features could not be confidently identified as foliation or bedding. Further limitations include the sampling biases created by the varying resistance of rock types and impassable terrain. More resistant rock types (i.e. basalt, quartzite) are overrepresented and less resistant rock types (i.e. serpentinite, argillite) are underrepresented in the field. Road cuts and streambeds provide the greatest exposure, but create a distribution bias in the location of analyzed outcrops.

The results of this project are captured by the attached map (see map). All mapped contacts are inferred due to the lack of exposure and structural controls. The contact between the Greyback Pluton and the Rattlesnake Creek Terrane is constrained with greater confidence than contacts within the mélange. The varying complexity between areas of the map is partially a function of outcrop density, as road cuts and larger streams expose more rock, and may create an artificial complexity distribution.

Barnard (2007) correlated rock type with vegetation, using changes in vegetation to infer contacts. The current study did not use vegetation as a rock type indicator. The only strong relationship between vegetation and rock type occurs within the marble. The marble hosts fewer conifers and more broad-leafed trees (i.e. madrones, manzanitas) than the surrounding bedrock. Though notable, these vegetation changes are not necessary for mapping because the marble is well exposed.

In the south portion of the mapped area, contacts trend NE/SW, which is generally consistent with the strike of foliation in the marble and quartzite in that area. However, this trend is not apparent in the rest of the mapped area, where no foliation data is available. Basalt and quartzite dominate this portion of the RCT.

Previous maps of the study area at a similar scale show an argillite matrix-supported mélange with blocks trending NE/SW. Current investigation reveals significantly more serpentinite than argillite, even in road cuts and stream cuts which should not be biased toward a specific lithology. What small amount of matrix is present is serpentinite and not argillite. The NE/SW orientation is only apparent in the southern portion of the mapped area and does not represent an overall trend.

Mapped Units

The rocks types are generally consistent with Barnard (2007), differing mainly in the current exclusion of gabbro, metasediment, and mélange as mapped units. Descriptions of mapped units follow:

The intrusive rocks of the Greyback Pluton (J pl) are resistant and moderately well-exposed. Weathered surfaces are dark grey with visible plagioclase crystals. Fresh surfaces are black and white. The rock is phaneritic and idiomorphic in texture and contains generally euhedral plagioclase, pyroxene, and hornblende. Mineral size and mode vary dramatically throughout the pluton; crystals range from less than one millimeter to nearly a centimeter and composition ranges from basaltic to andesitic. The contact between the Greyback Pluton and mapped units of the RCT is nonconformable. The main stage of the Greyback Pluton is dated to be 160 ± 2 Ma (Yule, et. al, 2006) indicating that it formed as the result of mantle derived magma during Jurassic subduction (Johnson and Barnes, 2006).

Meta-basalt (Tr b) is a ridge-former and weathers rusty orange, tan or white, or deep purple-ish red. Sulfide enrichment (pyrite) is evident in ~25% of outcroppings. The rock is dark grey to black and aphanitic in texture. Small, 1 mm to 5 mm vesicles are locally present. Very scarce olivine phenocrysts range in size from 1-3 mm. Locally, meta-diabase is found but is invariably accompanied by meta-basalt and is included within the meta-basalt unit. Diabase outcrops like basalt but lacks the sulfide enrichment and vesicles. Diabase is coarser than basalt, with subhedral crystals of plagioclase and pyroxene ranging from 1-3 mm in diameter. The contact between the meta-basalt and other members of the RCT is assumed to be a fault contact, though no direct evidence is seen.

Calcite marble (Tr ml) occurs as well-exposed, large outcrops. At outcrop scale, the marble has rounded edges and is white to medium grey. The sub-euhedral calcite crystals range in size from 1-5 mm in diameter. The rock is streaked with dark grey to pale blue planes of graphite from 0.1 cm to 4 cm thick. Graphite is largely acknowledged by scientists at the monument to be relict bedding from mats of bacteria growing in a paleo-ocean. The absence of known fossils in the marble indicates that the limestone formed shortly after the end-Permian extinction (~251 Ma). The low-grade metamorphism would not have eliminated fossil evidence. The limited extent of the known marble block suggests the source limestone may have been deposited on a seamount.

The skarn (Tr sk) associated with the marble forms dark grey ledges. Fresh surfaces are banded light grey, pale green, dark grey, white, and red. Stringers made of quartz, calcite, and garnet through a dark groundmass characterize the skarn.

Quartzite (Tr q) forms dark grey to light grey to white cliffs though color in hand-sample ranges from white, red, green, black, dark grey, or yellow. Most quartzite exhibits color banding in hand sample. Fresh surfaces display a sugary texture and sparkle with an aventurine luster in sunlight. Tr q also contains local chert, which is distinguished from quartzite by concoidal fracture and lack of sugary texture.

Slate, argillite, and phyllite, are included in the meta-pelite unit (Tr mp). The outcrop style of rocks within the meta-pelite unit (Tr mp) varies, ranging from poor exposure that blends into the surrounding soil, to well-exposed, prominent outcrop tens of meters in height. Most outcrops have a cleavage but this, too, ranges from blocky to shaley cleavage. The meta-pelite rocks are fine-grained and can be light grey to black. Most display reddish-orange weathering and some have a phyllitic sheen.

Serpentinite (Tr s) predominantly forms slopes though locally forms ledges. Tan to orange weathering is either pervasive through the outcrop or occurring as a 2 mm to 2 cm rind. The rock breaks along smooth polished surfaces. Fresh surfaces are black to green to yellow and display a vitreous fish-scale texture. Massive lizardite and antigorite dominate the rock. White, fibrous chrysotile is locally present. The serpentinite occurs as bands that appear to separate larger blocks within the mélange.

Partially serpentinized peridotite (Tr ps) forms ledges. Locally, the rock weathers orangey-red, but in most cases no weathering rind is present and the rock weathers black. Fresh surfaces are mottled brown and black. Relict green to brown pyroxenes (2-5 mm) compose 10 – 50% of the rock and are surrounded by a massive brown to black groundmass interpreted to be altered olivine.

Meta-igneous rock (Tr mi) appears only in road cuts and stream cuts. Weathering color is grey to tan. Fresh surfaces vary from grey to mottled black, grey, and white. In hand sample, the rock is disrupted by felsic veins and micro faults. Composition and texture vary on a centimeter scale, ranging from phaneritic to aphanitic, and felsic to mafic.

DISCUSSION

The Oregon Caves National Monument and surrounding area likely fall within the block-on-block mélange portion of the Rattlesnake Creek Terrane. This determination helps to better constrain the geologic history of the RCT and raises questions regarding the relationship between block-on-block mélange and block-in-matrix mélange.

The rocks are consistent with the described development of the RCT, specifically the altered intrusives in the NW portion of the mapped area, which likely resulted from arc magmatism in the Late Triassic to Early Jurassic (Wright and Wyld, 1994). The resulting volcanics form the cover sequence of the RCT. These intrusive rocks were deformed in conjunction with oceanic material during accretion of the island arc system, but the overlying cover sequence remained relatively undeformed (Wright and Wyld, 1994). Post-accretion magmatism is reflected in the undeformed Greyback Pluton, which brackets the compressional deformation at older than 160 Ma (Johnson and Barnes, 2006).

Wright and Wyld (1994) divide the RCT into two categories: the lower serpentinite matrix mélange and the upper coherent volcaniclastic cover sequence. The seven square miles investigated in the current study do not match either of these categories. Serpentinite makes up less than 15% of the total rock, indicating that is does not act as a matrix; the serpentinite matrix-supported mélange described by Wright and Wyld (1994) consists of 50% serpentinite. While the proportions of rock types differ, the lithologies observed in the mélange portion of the RCT by Wright and Wyld (1994) are generally consistent with those found in the current study area, with the exception of moderate- to high-grade metamorphic rocks such as amphibolite. The abundance of meta-basalt found in the study area is the most notable difference from the mélange described by Wright and Wyld (1994); ~50% of the rock in the current study area is meta-basalt while only ~10% of the mélange blocks observed by Wright and Wyld (1994) are meta-basalt. If not for the lack of coherent volcaniclastic sequences associated with the meta-basalt, the high proportion of volcanic material would place the study area in the cover sequence of the RCT.

The mélange-type lithologies in conjunction with the abundance of meta-volcanics may indicate that the study area is located at the transition zone between the matrix-supported mélange and the cover sequence. However, it seems more likely that the study area correlates with the Bolan Lake area of the RCT described by Donato et al. (1996) as block-on-block mélange with interstitial serpentinite metamorphosed to greenschist facies. Wright and Wyld (1994) describe the transition zone mélange as containing blocks of cover sequence strata. No coherent volcaniclastic sequences were found in the present study area. In addition, the volcanics described by Wright and Wyld include augite or quartz porphyry which are also absent.

The geographic proximity and the lithologic similarities between the Bolan Lake area and the current study area support the interpretation that they are part of the same subdivision of the RCT. Located only ~12 km from Oregon Caves National Monument, the Bolan Lake area is described as a block-on-block portion of the ophiolitic mélange. Serpentinite is not pervasive in the Bolan Lake area. It exists as discontinuous lenses within and between blocks rather than as a matrix (Donato et al., 1996). Serpentinite in the study area is similarly isolated and also occurs as lenses. Blocks of basalt and amphibolite are more common in the Bolan Lake area than in the matrix-supported mélange areas; making up approximately 50% of the rocks in the block-on-block mélange (Donato et al. 1996). Despite the lack of amphibolite-facies rock, the proportion of massive basalt in the current study area matches that of the Bolan Lake area. The Bolan Lake area and the current study area are interpreted to be correlate block-on-block sections of the mélange. The connections between the current study area and the Bolan Lake area imply that the block-on-block portion of the Rattlesnake Creek mélange seen at both locations is not an artifact of differential exposure, as suggested by Wright and Wyld (1994) but rather a meaningful spatial variation.

The geologic history leading to the development of both a block-on-block and block-in-matrix mélange in close proximity is not understood. The petrogenesis of the RCT detailed by Wright and Wyld (1994) does not consider the development of a block-on-block mélange. Given that the current study expands the known extent of block-on-block mélange in the RCT, further investigation into block-on-block mélange generation is of interest. The nature of the contact between the volcaniclastic cover sequence and the underlying mélange differs between the described type-localities of the two mélange types. The cover sequence is in depositional contact with the serpentinite-matrix mélange but is in faulted contact with the block-on-block mélange (Wright and Wyld, 1994; Donato et al., 1996). The current study does not locate the contact between the mélange and the overlying volcaniclastic cover sequence. Given the potential association between mélange type and relation to the cover sequence, future investigations into the nature of the contact in the current study area are advised. Understanding the relationship of the mélange to the cover sequence could help illuminate the connection between the two mélange types.

CONCLUSION

The current geologic map provides a detailed look into the often undifferentiated Rattlesnake Creek Terrane. The block-on-block nature of this portion of the mélange and the connection with the previously described Bolan Lake area to the south offer new insights and raise new questions about the phases of mélange development in the RCT. Further mapping may be able to delineate the block-on-block portion of the mélange from the block-in-matrix portion; linking geographic expression to accretionary processes.

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